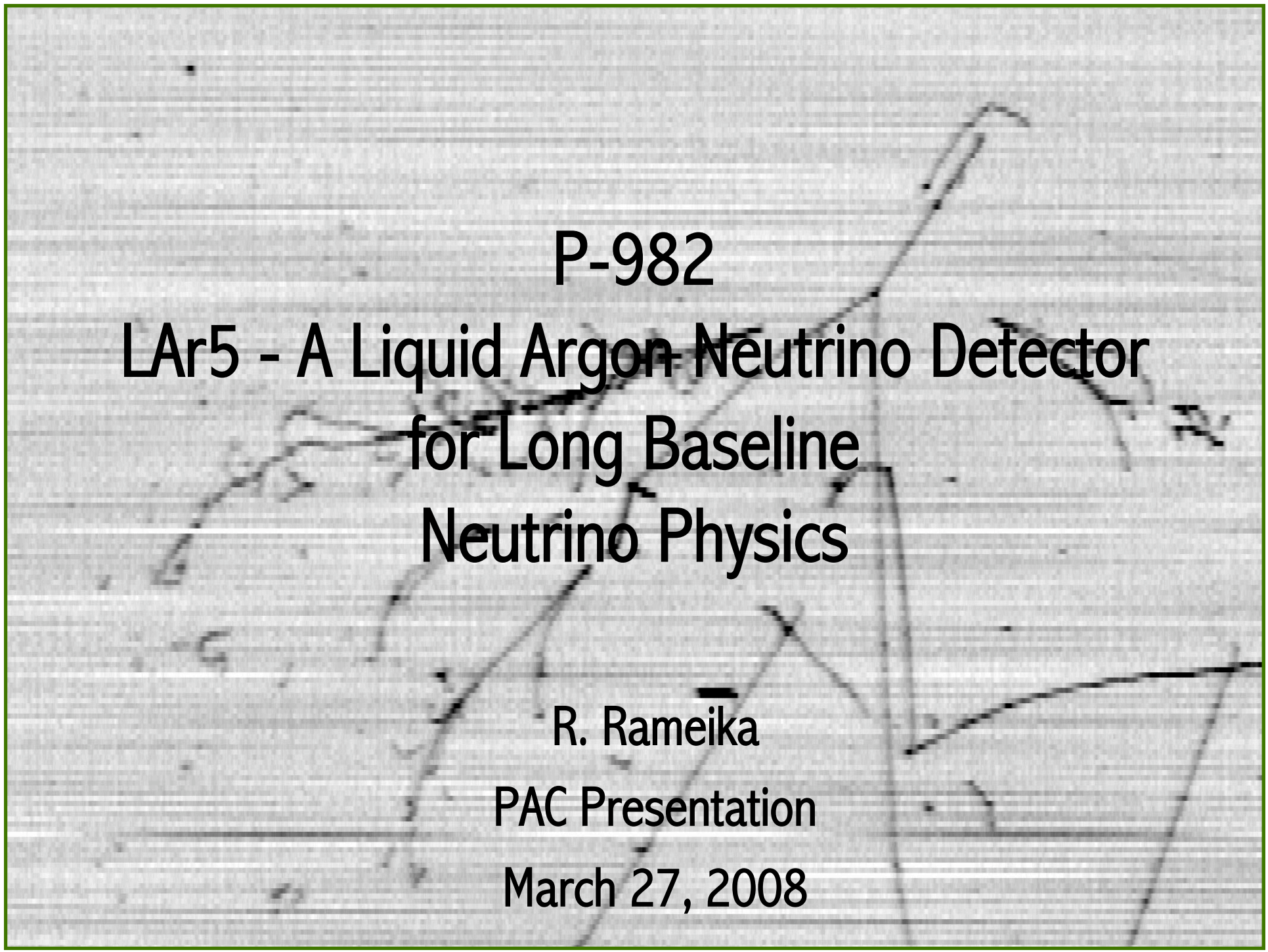


P-982
LAr5 - A Liquid Argon Neutrino Detector for Long Baseline Neutrino Physics

R. Rameika

PAC Presentation

March 27, 2008

Outline

- The Physics Case
- LAr detector development
- Siting Options
- Technical Challenges
- Physics Potential
- Schedule
- Conclusion

An Exciting Time in Neutrino Physics

- Neutrinos have mass - detectable by measuring neutrino flavor oscillations
  - $\nu_e \rightarrow \nu_\mu$ (solar experiments, Kamland)
  - $\nu_\mu \rightarrow \nu_\tau$ (atmospheric experiments, K2K, MINOS)
- Within the next few years we will have our first look beyond the Chooz limit to see whether or not the mixing angle , $\theta_{13,}$ is "large"
- Large or "small" we have a plan* for what we need to do :
  - Measure θ_{13}
  - Determine the neutrino mass ordering
  - Search for CP violation in the neutrino sector

*Report of the US long baseline neutrino experiment study can be found at http::nwg.phy.bnl.gov/~diwan/nwg/fnal-bnl

Recommendations to the Department of Energy and the National Science Foundation on a Future U.S. Program in Neutrino Oscillations can be found at http::www.science.doe.gov/hep/NUSAGFinalReportJuly13,2007.pdf

The Plan/Vision

- We can design future experiments (using conventional* neutrino beams) to have 3-5σ discovery potential for measuring $\sin^2 2\theta_{13}$, CP violation and the neutrino mass hierarchy
- If $0.001 < \sin^2 2\theta_{13} < 0.01$ reaching these sensitivities will require reached :
  - a proton source at the Megawatt level (or decades of running time)
  - a neutrino beam optimized to the oscillation probability (covering the 1st and 2nd oscillation maximum)
  - an experiment baseline > 1000 km (to improve the sensitivity to determine the mass hierarchy)
  - a Detector with mass x efficiency ~50-100kT

*If nature has made θ_{13} very small we may need to move beyond conventional beams, i.e. neutrino factory

July 2007
Recommendations from NuSAG

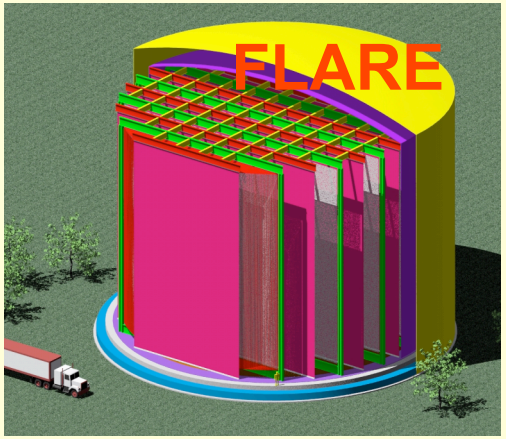
- **Recommendation 1.** The US should prepare to proceed with a long baseline neutrino oscillation program to extend sensitivity to $\sin^2 2\theta_{13}$, to determine the mass ordering of the neutrino spectrum, and to search for CP violation in the neutrino sector. Planning and R&D should be ready for a technology decision* and a decision to proceed when the next round of results on $\sin^2 2\theta_{13}$ becomes available, which could be as early as 2012. A review of the international program in neutrino oscillation and the opportunities for international collaboration should be included in the decision to proceed.
  - * Two candidate technologies :
    - Water Cherenkov
      - Low efficiency → LARGE
      - Existence proof : SuperK
    - Liquid Argon TPC
      - High efficiency → SMALLER
      - Existence proof :TBD
  - *In the past year a community consensus is emerging that both technologies have a lot of merit and we are beginning to envision a future program in which both evolve*

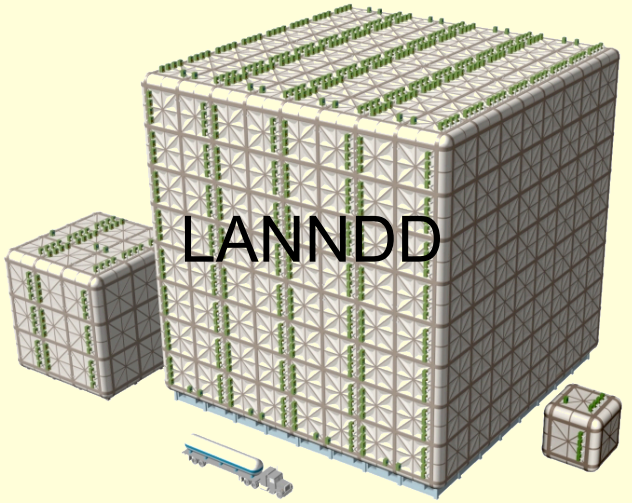
July 2007
Recommendations from NuSAG

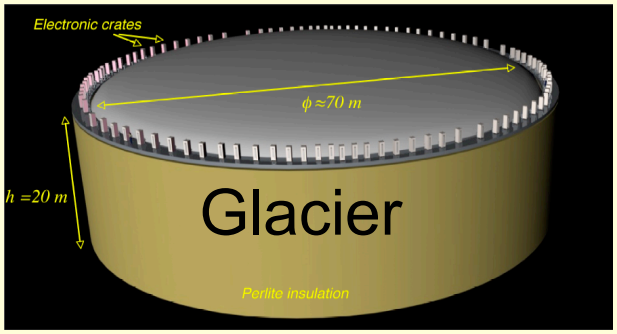
- **Recommendation 4.** A phased R&D program with milestones and using a technology suitable for a 50-100 kton detector is recommended for the liquid argon detector option. Upon completion of the existing R&D project to achieve purity sufficient for long drift times, to design low noise electronics, and to qualify materials, construction of a test module that could be exposed to a neutrino beam is recommended.

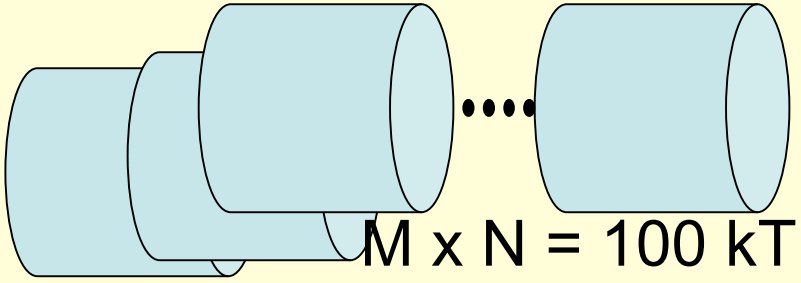
July 2007
Recommendations from NuSAG

- **Recommendation 4.** A phased R&D program with milestones and using a technology suitable for a 50-100 kton detector is recommended for the liquid argon detector option. Upon completion of the existing R&D project to achieve purity sufficient for long drift times, to design low noise electronics, and to qualify materials, construction of a test module that could be exposed to a neutrino beam is recommended.

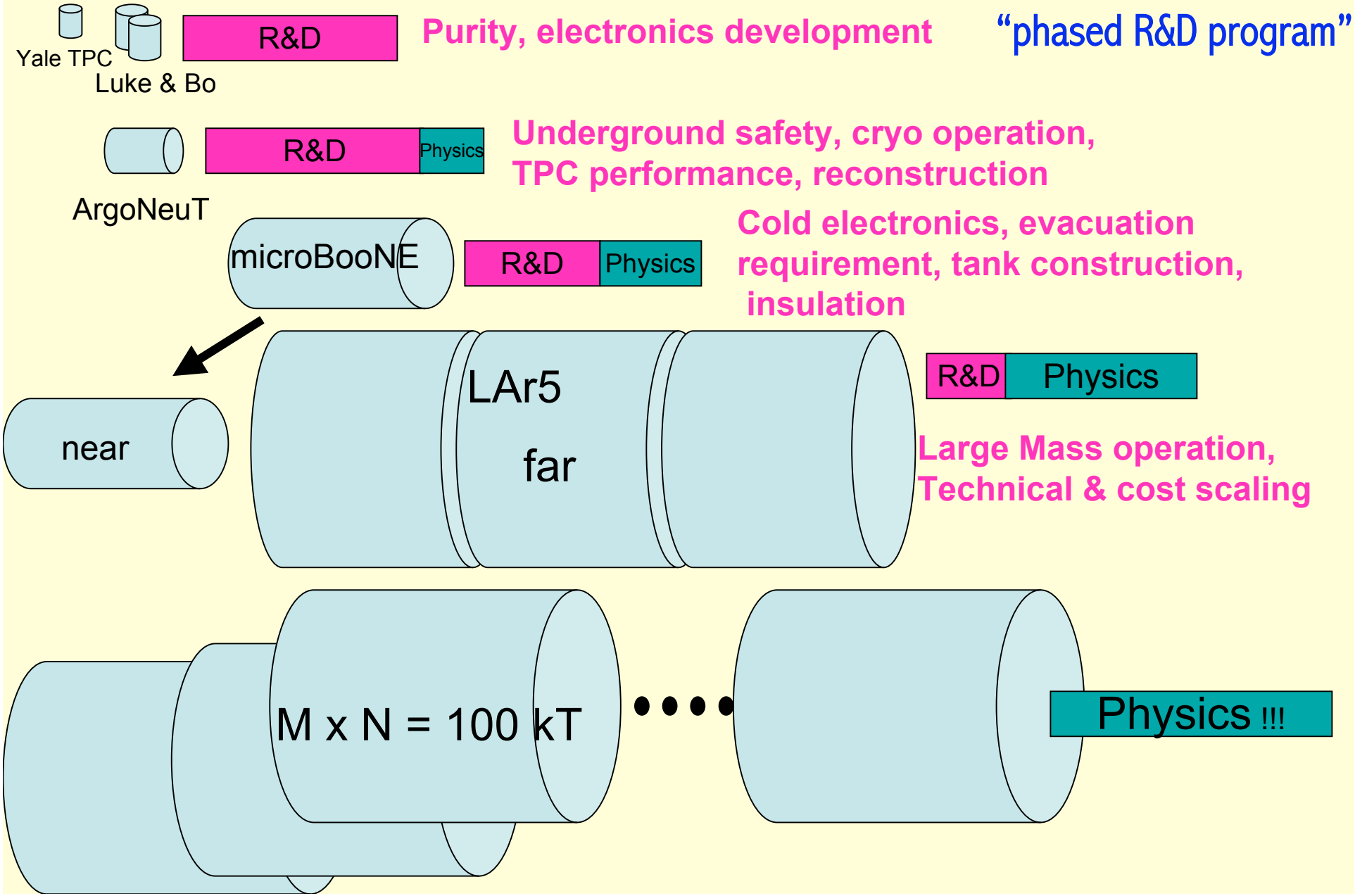








Evolution of the Liquid Argon Physics Program



Technical Issues

Many technical issues will be addressed directly in the design, construction, and operation of the MicroBooNE detector, however for the larger scale there are many more unique issues

- Design Considerations
  - Liquid Argon purity → maximum drift → channel count
  - Thermal insulation → Operation cost
  - Location : surface/underground
    - Mechanical stability and safety → cryostat design
    - Cosmic ray backgrounds
  - ….
- Scaling considerations
  - Modularity
  - Shape
  - Total-Fiducial-Active volume ratio
  - Number of electronic channels
  - Surface-to-volume ratio (heat input and wall outgassing)
  - Cryostat thermal insulation techniques
  - Materials and construction techniques

Why a 5 kiloton step?

- From a purely technical point of view, the step after the 100 - 200 t detector, could be 1 to 5 kilotons
  - The main technical purpose of this step is to determine construction techniques and the scaling laws, especially in regards to cost
- Location of 1 - 5 kilotons
  - 1 kT in a near location gets lots of events; does near detector physics - no oscillation physics
  - 5 kT in a far location is about the smallest one can build and have decent sensitivity to physics measurements

5kT is an appropriate step in mass and has compelling physics potential

Similar idea evolving in Europe :Project MODULAr

A new, very massive modular Liquid Argon Imaging Chamber to detect low energy off-axis neutrinos from the CNGS beam.

(Project MODULAr)

B. Baibussinov[1], M. Baldo Ceolin[1], G. Battistoni[2], P. Benetti[3], A. Borio[3], E. Calligarich[3], M. Cambiaghi[3], F. Cavanna[4], S. Centro[1], A. G. Cocco[5], R. Dolfini[3], A. Gigli Berzolari[3], C. Farnese[1], A. Fava[1], A. Ferrari[2], G. Fiorillo[5], D. Gibin[1], A. Guglielmi[1], G. Mannocchi[6], F. Mauri[3], A. Menegolli[3], G. Meng[1], C. Montanari[3], O. Palamara[1], L. Periale[6], A. Piazzoli[3], P. Picchi[6], F. Pietropaolo[1], A. Rappoldi[3], G.L. Raselli[3], C. Rubbia[AI][4], P.Sala[2], G. Satta[5], F. Varanini[3], S. Ventura[1], C. Vignoli[3]

[1]*Dipartimento di Fisica e INFN, Università di Padova, via Marzolo 8, I-35131*
[2]*Dipartimento di Fisica e INFN, Università di Milano, via Celoria 2, I-20123*
[3]*Dipartimento di Fisica Nucleare, Teorica e INFN, Università di Pavia, via Bassi 6, I-27100*
[4]*Laboratori Nazionali del Gran Sasso dell'INFN, Assergi (AQ), Italy*
[5]*Dipartimento di Scienze Fisiche, INFN and University Federico II, Napoli, Italy*
[6]*Laboratori Nazionali di Frascati (INFN), via Fermi 40, I-00044*

Abstract.

The paper is considering an opportunity for the CERN/GranSasso (CNGS) neutrino complex, concurrent time-wise with T2K and NOvA. It is a preliminary description of a ≈ 20 kt fiducial volume Liquid Ar TPC following very closely the technology developed for the ICARUS-T600, which will be operational as CNGS2 early in 2008.

The present preliminary proposal, called MODULAr, is focused on the following three main activities, for which we seek an extended international collaboration:

(1) *the neutrino beam* from the CERN 400 GeV proton beam and an optimised horn focussing, eventually with an increased intensity in the framework of the LHC accelerator improvement programme.

(2) A *new experimental area* LNGS-B, of at least 50'000 m^2 at 10 km off-axis from the main Laboratory, eventually upgradable to larger sizes. As a comparison, the present LNGS laboratory has three halls for a total of 180'000 m^3. A location is under consideration at about 1.2 km equivalent water depth. The bubble chamber like imaging and the very fine calorimetry of the LAr-TPC detector will ensure the best background recognition not only from the off-axis neutrinos from the CNGS but also for proton decay and cosmic neutrinos.

(3) *A new LAr imaging* detector, at least initially with about 20 kt fiducial mass. Such an increase in the volume over the current ICARUS T600 needs to be carefully considered. It is concluded that a single, huge volume of such a magnitude is uneconomical and inoperable for many reasons. A very large mass is best realised with a modular set of many identical, but independent units, each of about 5 kt, "cloning" the basic technology of the T600. Several of such modular units will be such as to reach at least 20 kt as initial sensitive volume. Further phases may foresee extensions of MODULAr to a mass required by the future physics goals.

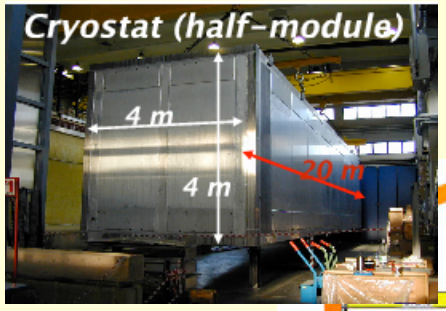
Compared with large water Cherenkov (T2K) and fine grained scintillators (NOvA), the LAr-TPC offers a higher detection efficiency for a given mass and lower backgrounds, since virtually all channels may be unambiguously recognized. In addition to the search for θ_{13} oscillations and CP violation, it would be possible to collect a large number of accurately identified cosmic ray neutrino events and perform search for proton decay in the exotic channels.

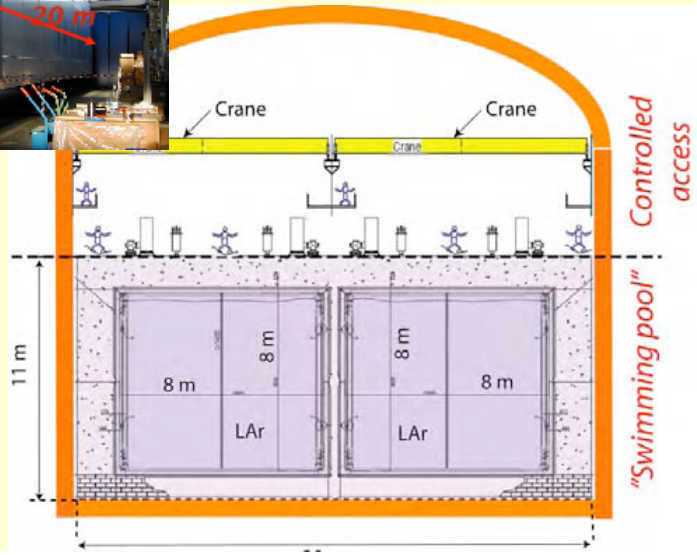
The experiment might reasonably be operational in about 4/5 years, provided a new hall is excavated in the vicinity of the Gran Sasso Laboratory and adequate funding and participation are made available.

(April 9,2007)

[AI] Corresponding author: Carlo.Rubbia@cern.ch

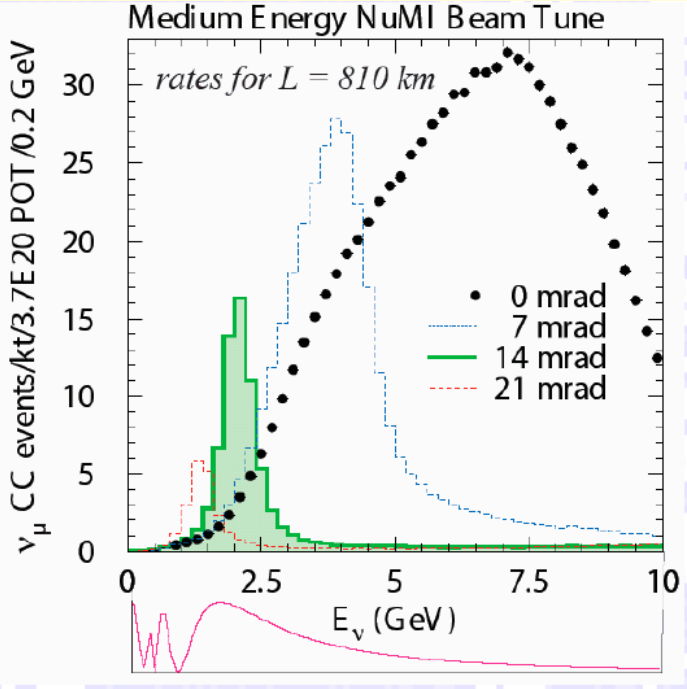
- ~20kT fiducial volume, modeled after ICARUS T-600
  - Upgraded neutrino beam from the 400 GeV CERN SPS
  - New experimental area 10 km off-axis of CNGS neutrino beam
  - Multiple 5kT LArTPCs
    - (8x8x60m^3 per 5kT unit)



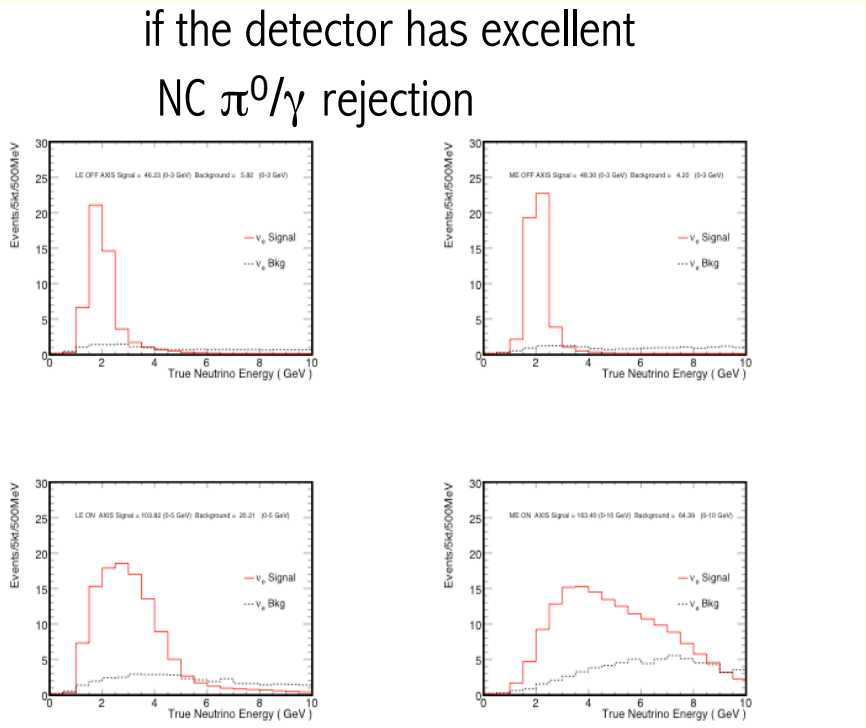


Detector Siting Options

- Off-axis neutrinos
  - Reduced backgrounds from neutral current interactions
    - Reason for NOvA choice
  - Lower the energy to get closer to the oscillation maximum
    - Reason for the MODULAr choice

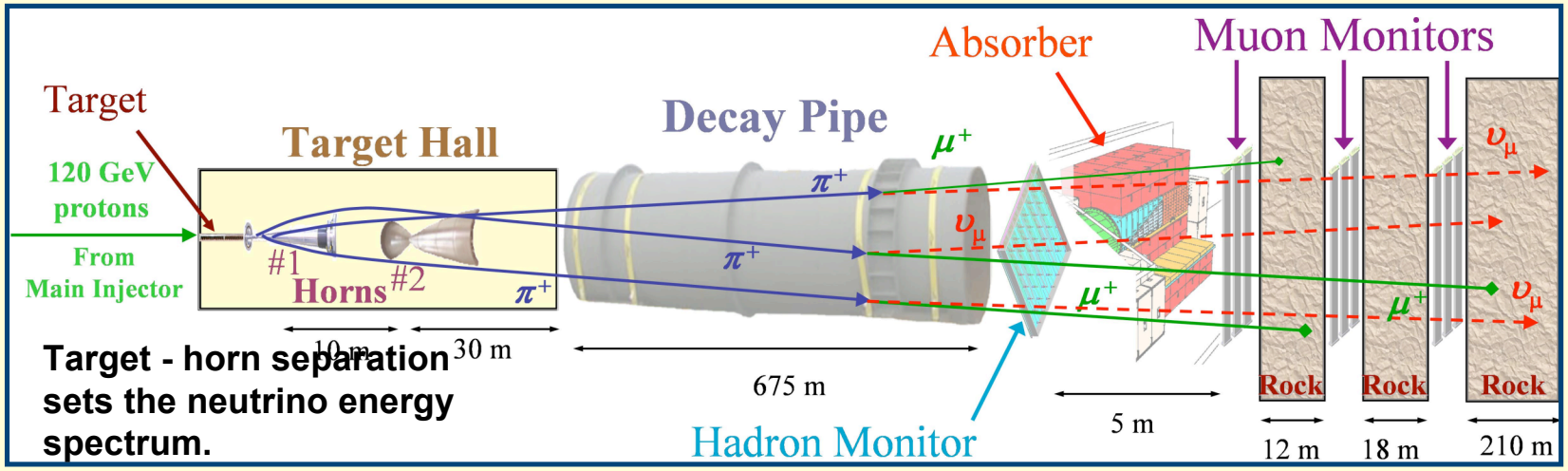


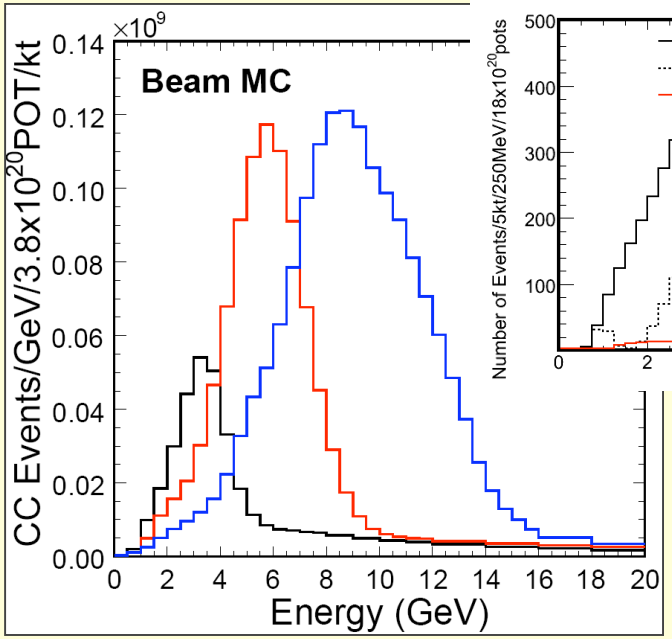
- On-axis neutrinos
  - Broadband beam : more events, both signal and background
  - On-axis option can be considered if the detector has excellent NC π^0/γ rejection

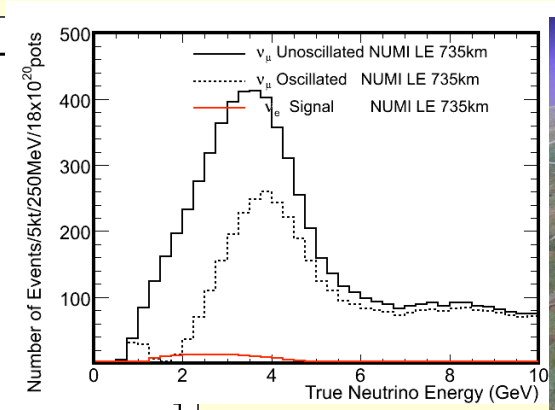


ν_e signal for $\sin^2 2\theta_{13} = 0.1$

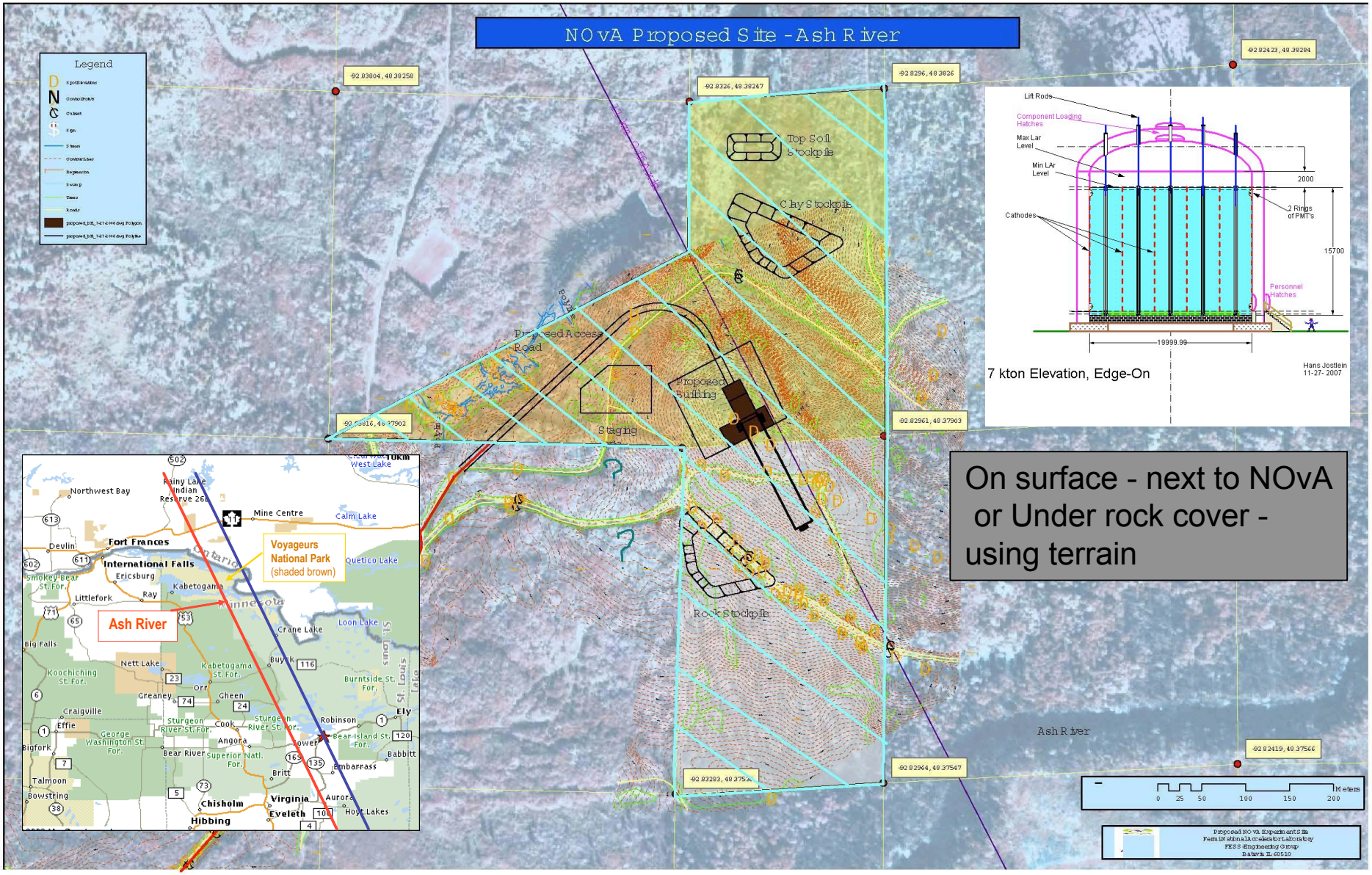
The NuMI Beam





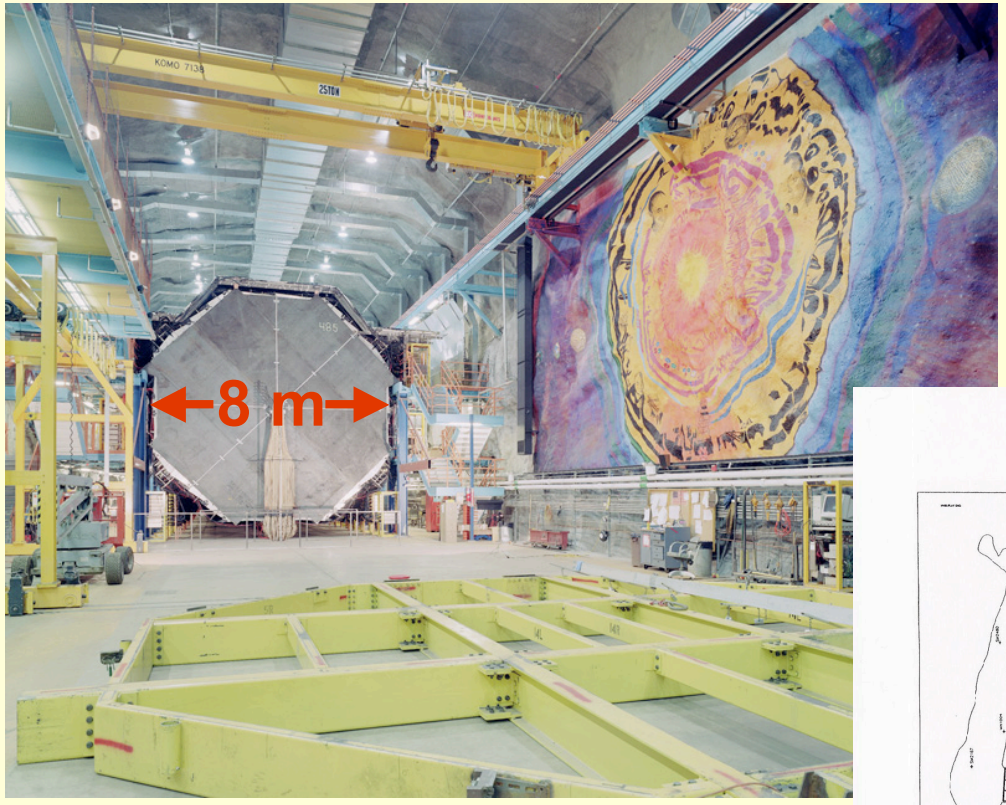


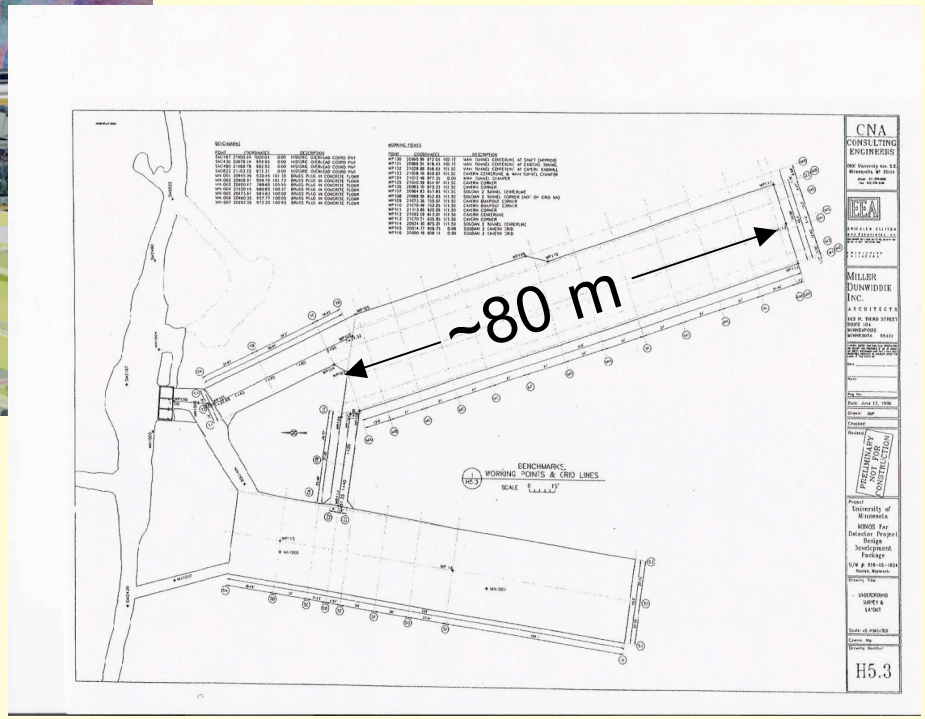
Siting options at Ash River



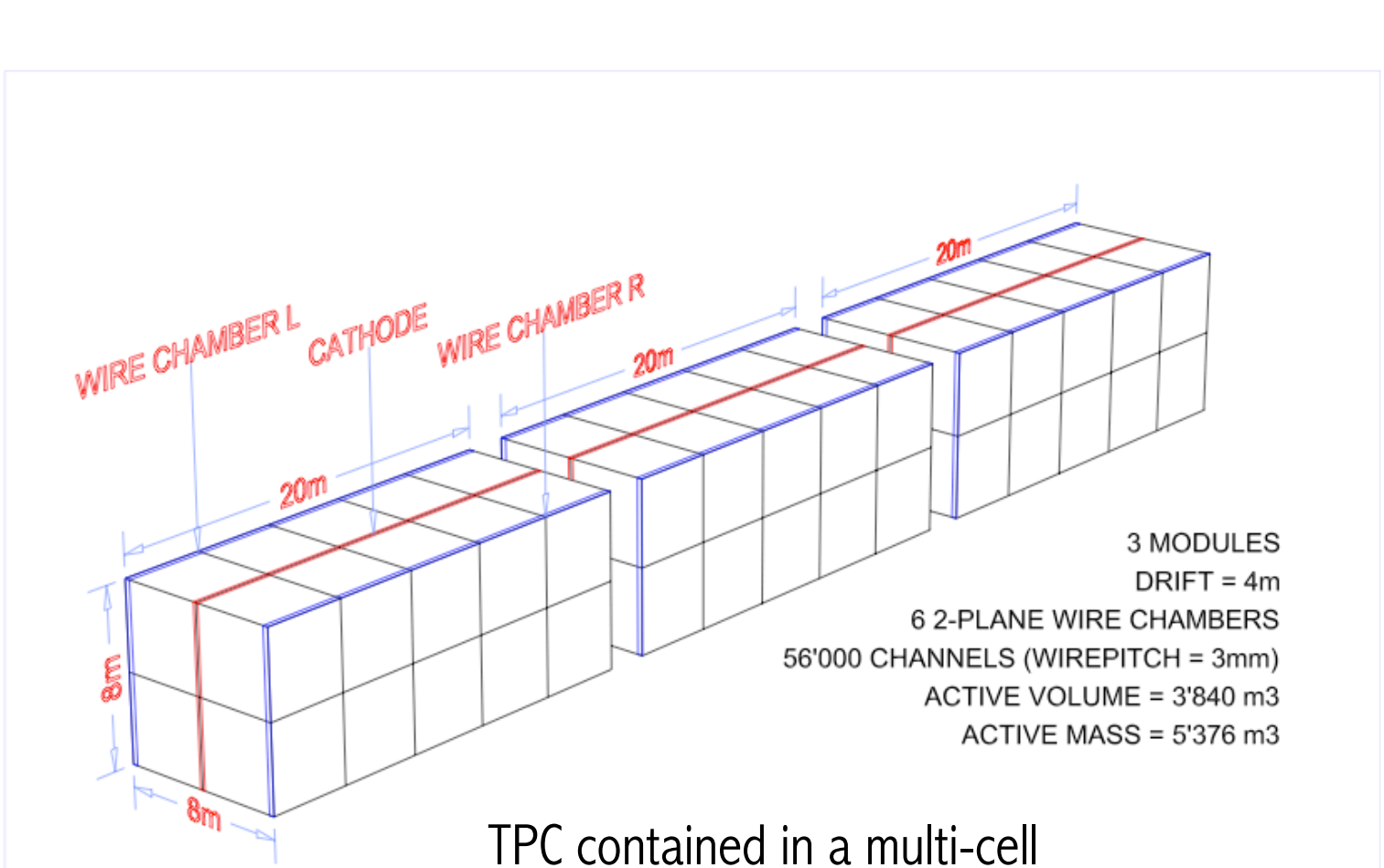
On surface - next to NOvA or Under rock cover - using terrain

The MINOS Cavern at the Soudan Underground Laboratory





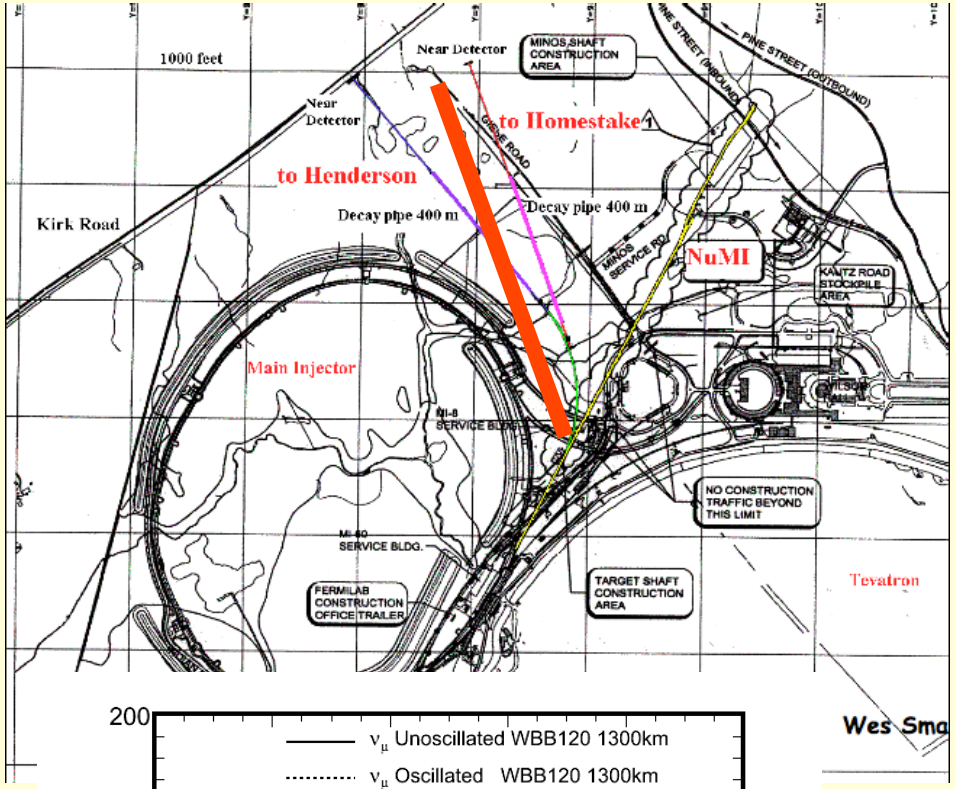
LANNDD Modular Concept

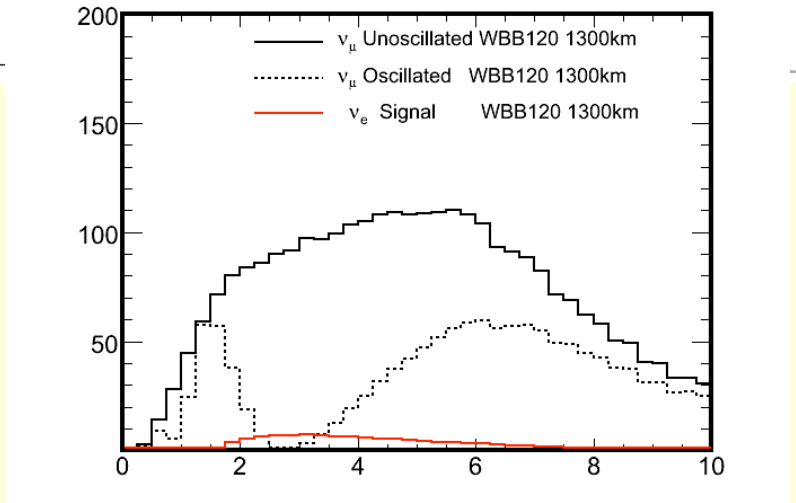


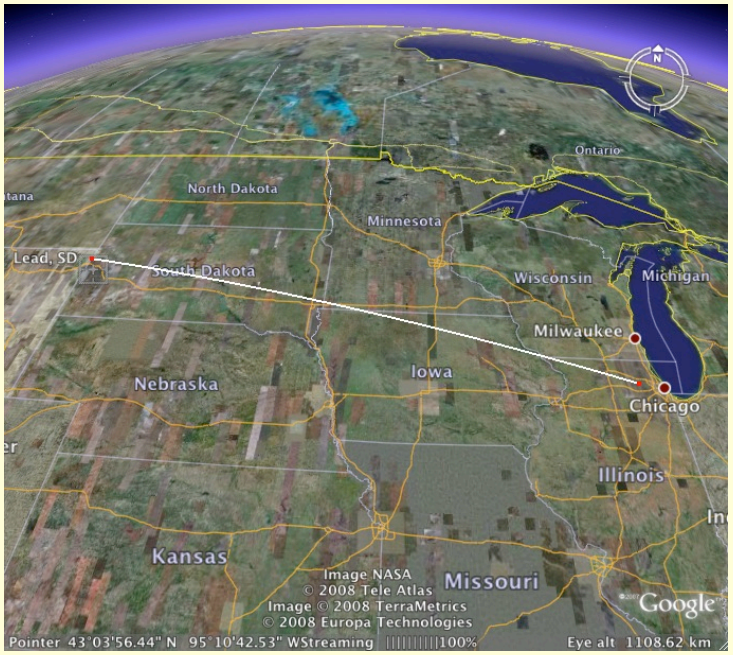
TPC contained in a multi-cell mechanical structure

Drawing courtesy of D. Cline and F. Sergiampietri

The DUSEL Option





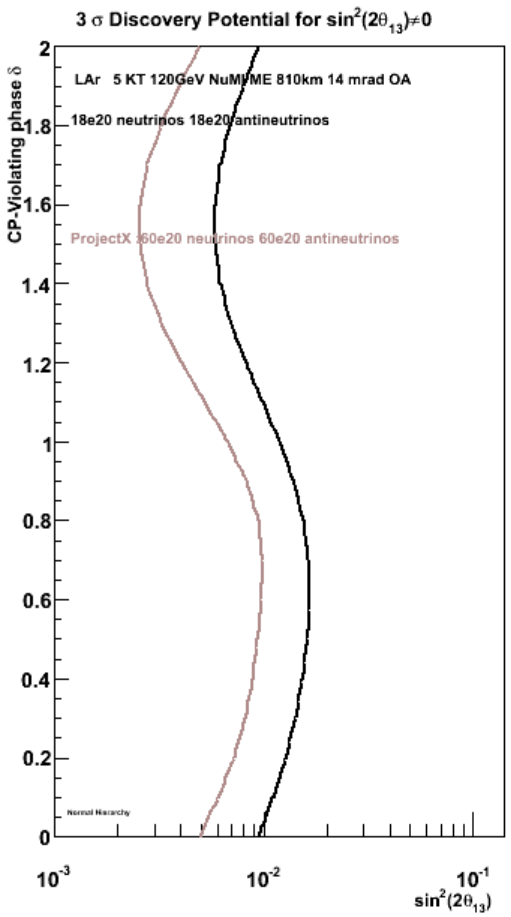


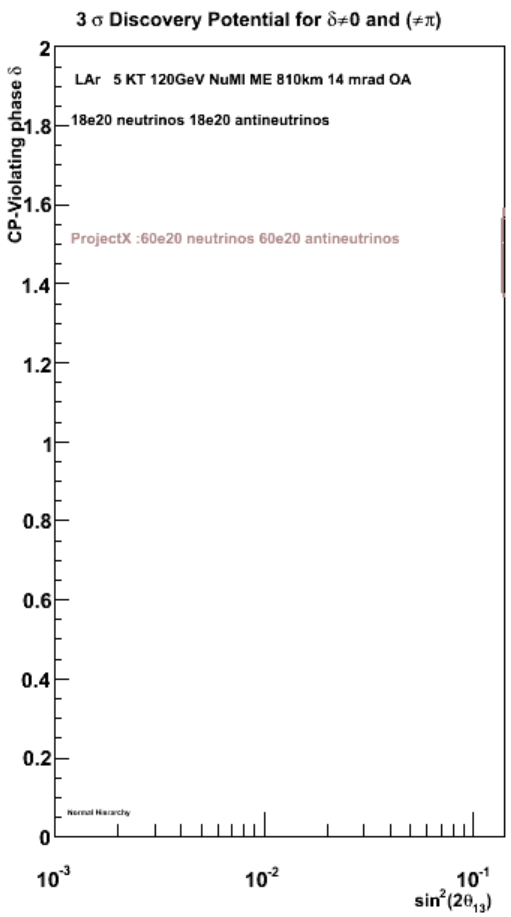
L = 1300 km (more matter effect in the oscillations

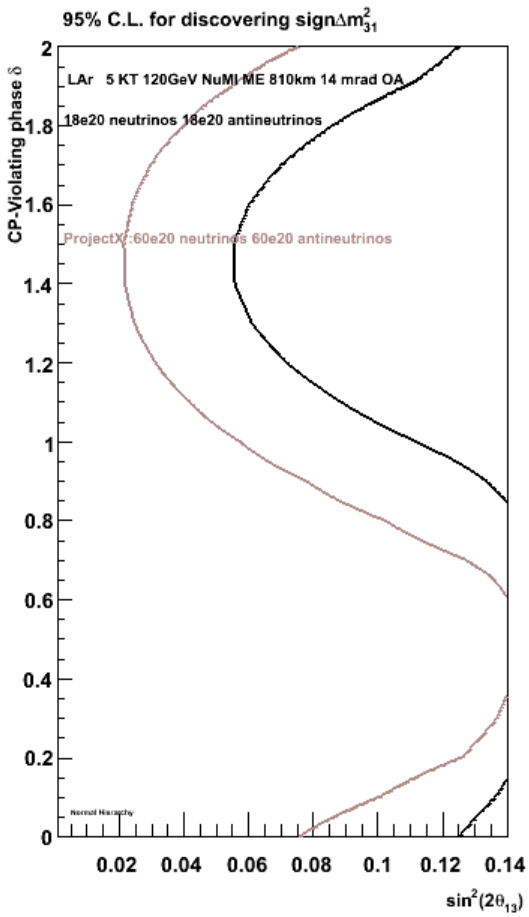
Oscillation maximum at higher energies

Broad band beam can cover 1st and 2nd maximum

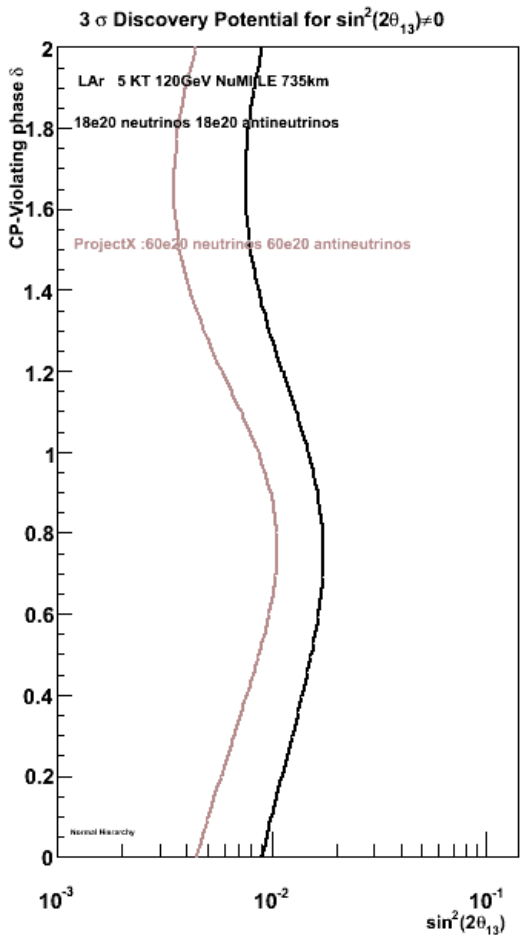
LAr5 @ Ash River (ME)

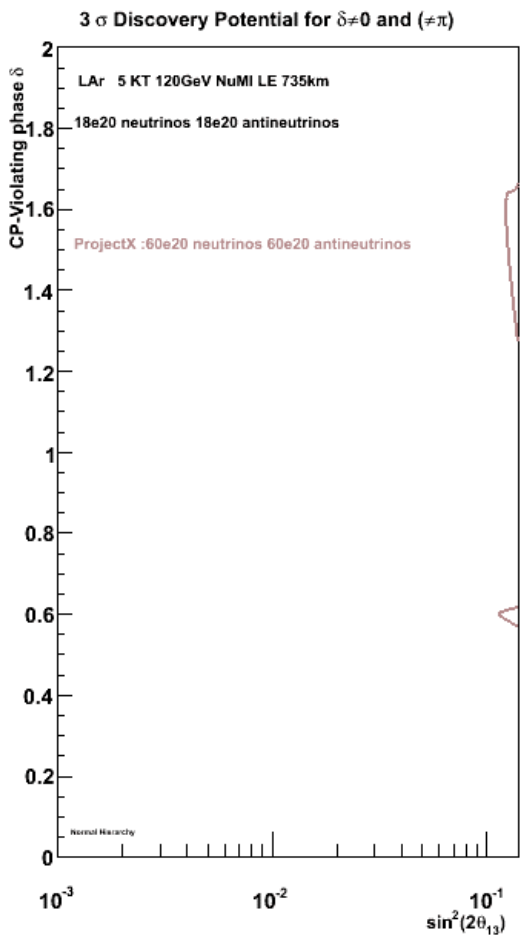


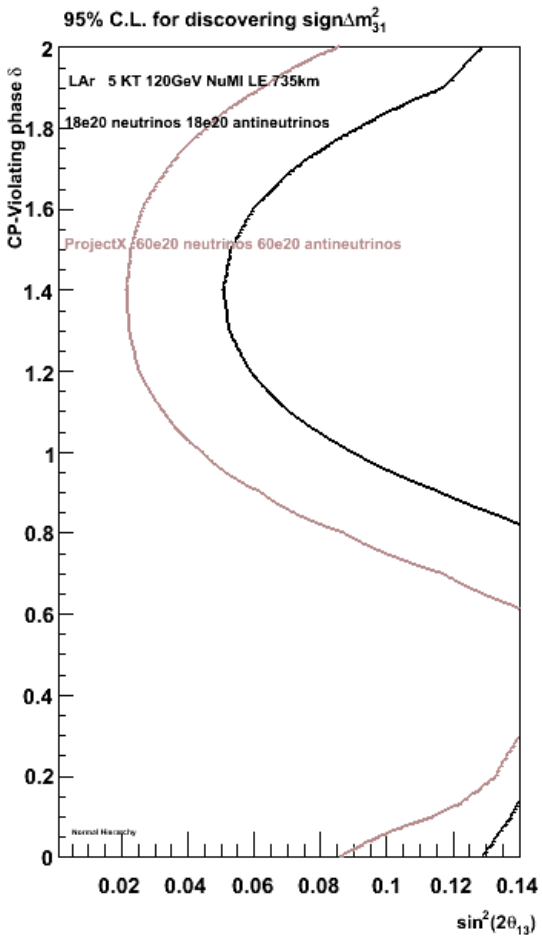




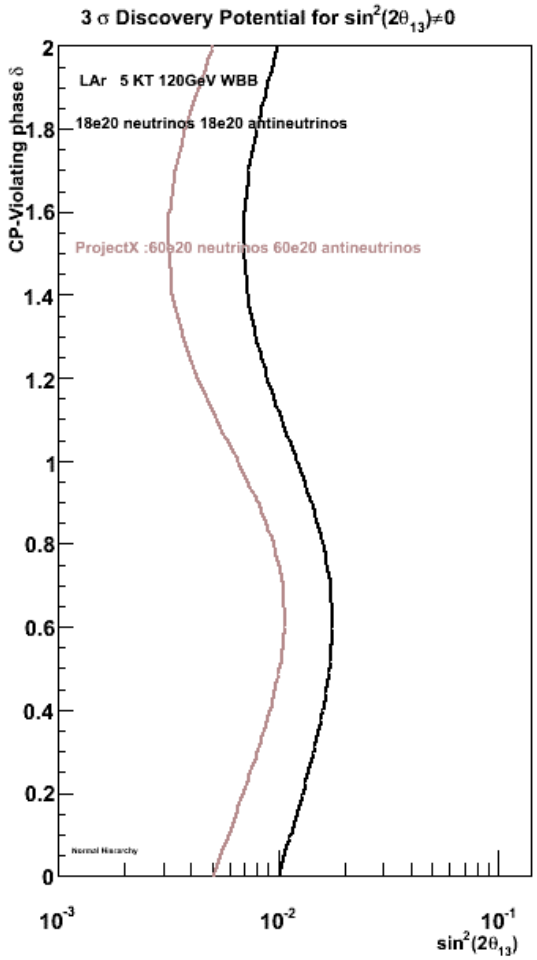
LAr5 @ SOUDAN (LE)

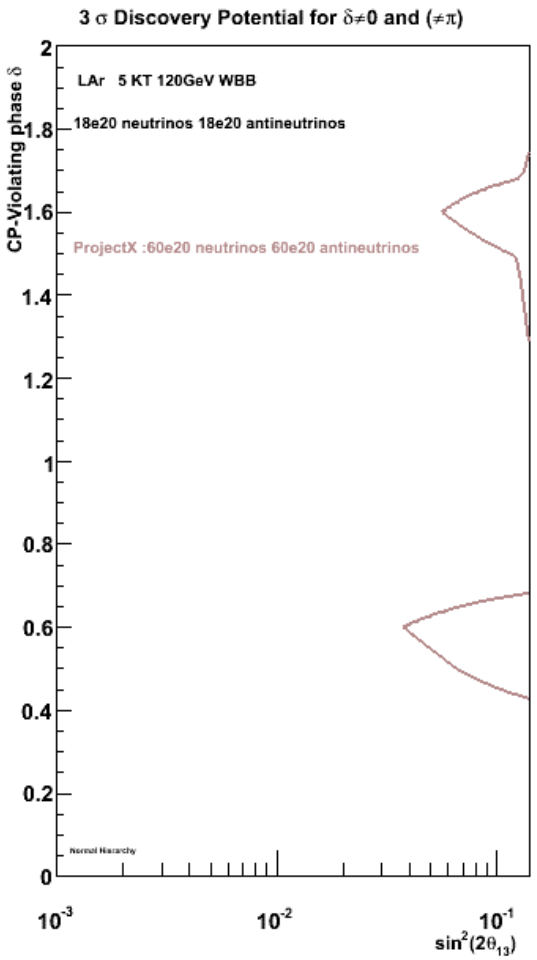


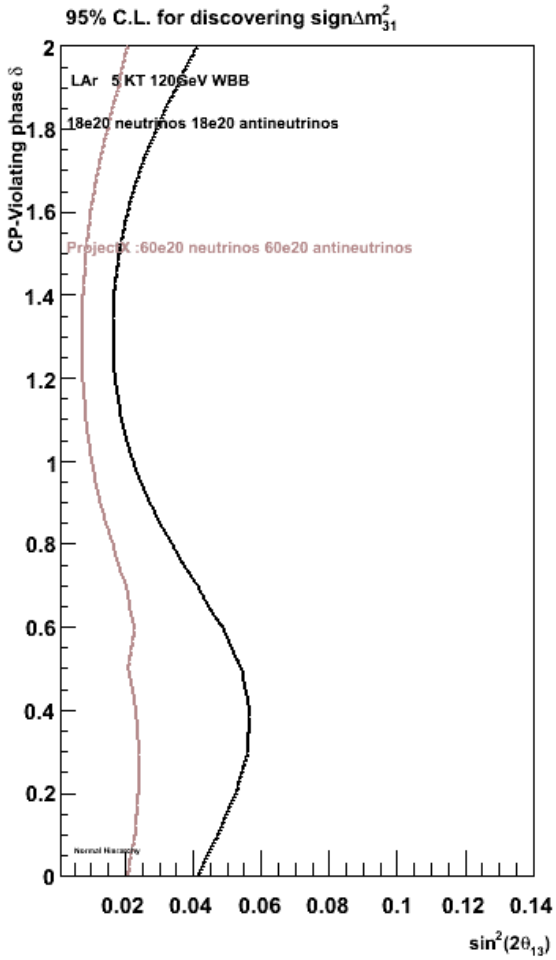




LAr5 @ L = 1300 km







Pros and Cons of the NuMI Options

- Pros :
  - The NuMI beam exists; it will be upgraded to 700kW for NOvA
  - Ash River
    - The Ash River site will be developed for NOvA; LAr5 could benefit from the infrastructure
  - Soudan
    - The SOUDAN cavern + laboratory infrastructure exists; MINOS will complete its running ~2011; disassembly and removal of MINOS was built into the planning
    - The cavern holds a maximum of ~5kT : no scope creep!
    - Requires us to address underground construction & operation
    - The underground location eliminates the concern about surface operation (which in principle is possible, but likely to lead to additional challenges)
      - Any detector constructed for proton decay will need to be at depth
      - This 5kT may be able to make a contribution to the $p \rightarrow K\nu$ search
  - Physics reach is comparable to NOvA → ~doubling the mass

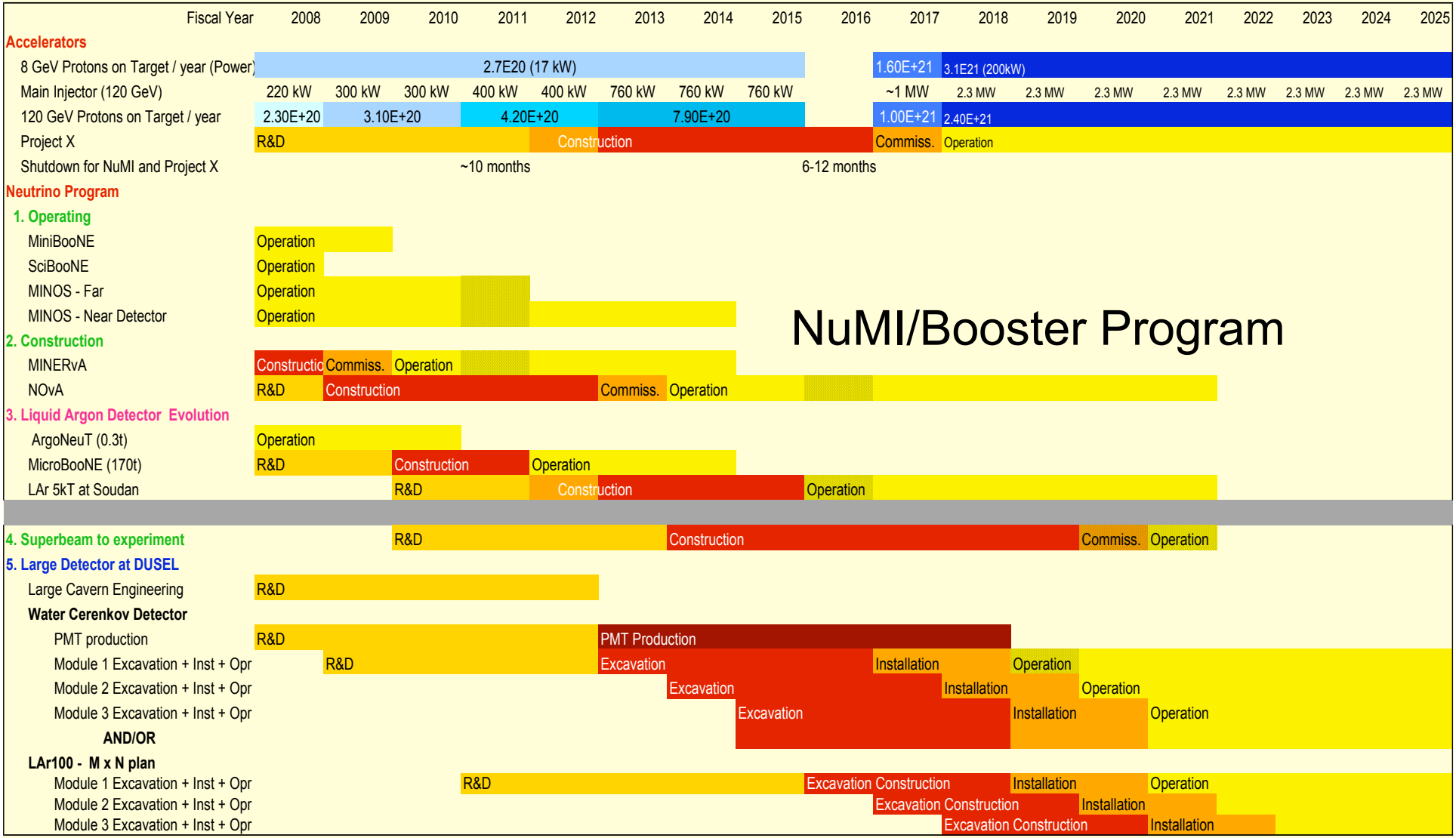
Pros and Cons of the NuMI Options

- Cons :
  - The NuMI beam exists; the baseline is limited to 735km on axis and 810 km off-axis; the decay pipe geometry is optimized for high energy
  - The Ash River site is being developed for NOvA; additional site development might not be practical on a fast time scale
  - The Soudan cavern holds a maximum of ~5kT : no upgrade path
  - Physics reach is comparable to NOvA : good for θ_{13}, limited for mass hierarchy

Pros and Cons of the DUSEL Option

- Cons :
  - The DUSEL beam doesn't exist; minimum 5 year, >$200M construction project
  - DUSEL caverns do not exist, even for 5 kT; preliminary estimate at 300' level ~$25M
- Pros :
  - The DUSEL beam doesn't exit : we can design an optimized beam
  - The cavern doesn't exist ; can be planned for future expansion
  - Two options for depth : 300' drive-in, 4850' to be developed
  - The underground location eliminates the concern about surface operation (which in principle is possible, but likely to lead to additional challenges)
    - Any detector constructed for proton decay will need to be at depth
    - This 5kT may be able to make a contribution to the $p \rightarrow K\nu$ search
  - Plans for an early implementation in progress (SUSEL) [April Workshop]
  - Physics reach for θ_{13} is comparable to NOvA; better for mass hierarchy
  - Eventually sensitivity to CP Violation

Schedule considerations



Conclusions

- We believe that a 5 kiloton liquid argon neutrino detector is the appropriate size to plan for the next step (after MicroBooNE) in developing this detector technology
- A 5kT detector has powerful physics potential, in either the NuMI or DUSEL locations
- The major technological design issues that will be addressed in our Proposal are :
  - Cryostat/TPC configuration
  - Installation/construction techniques
  - Mitigation of safety issues (containment, egress)
  - Per channel cost of electronics
  - Total Project Cost estimate
- We request **engineering and design support** to develop a Proposal
- Given appropriate support and encouragement we will organize into a more formal collaboration structure
- We would aim to have a Proposal ready one year from now

Contributors and Potential Collaborators

B. Baller, D. Finley, D. Jensen, H. Jostlein, C. Laughton, B. Lundberg,
R. Plunkett, S. Pordes, R. Rameika[1], N. Saoulidou, R.Schmitt
Fermi National Accelerator Laboratory

M. D. Messier, J. Musser, J. Urheim
Indiana University

C. Bromberg, D. Edmunds
Michigan State University

K. Heller, M. Marshak, E. Peterson
University of Minnesota

T. E. Coan
Southern Methodist University

S. Kopp, K. Lang
University of Texas, Austin

H. Gallagher, W. A. Mann, J. Schneps
Tufts University

B. Fleming
Yale University

[1]Contact : rameika@fnal.gov